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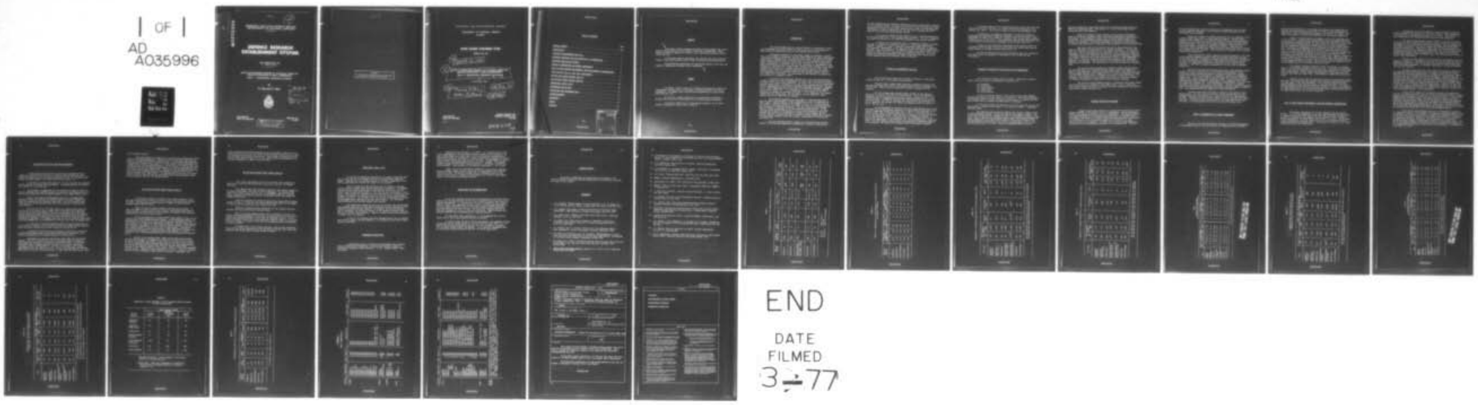

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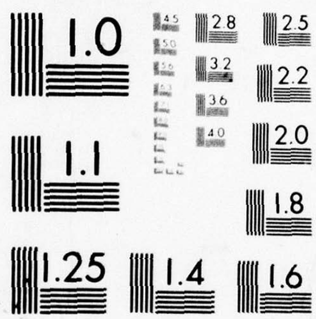

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SURVEY OF CONTINUOUS SOURCES OF ELECTRICAL POWER FOR UNDER-ICE PROPULSION OF SMALL SUBMERSIBLES

PART I: CONVENTIONAL SECONDARY BATTERIES

by

T.E. King and W.J. Moroz

DSS CONTRACT
SERIAL NO. 2SR5-0007

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ABSTRACT

This report reviews candidate secondary battery systems that can be used for the propulsion of the Canadian Forces SDL-1 submersible. These battery systems are compared in terms of their physical and chemical characterics and cost.

Of the power sources considered, the improved flat plate lead acid battery is the most suitable choice to meet the present 300 Ah application.

The silver/zinc system with its high energy density is the only one capable of meeting the forecast 800 Ah requirement.

RÉSUMÉ

Le présent rapport examine les systèmes d'accumulateurs (batteries rechargeables) pouvant servir à propulser le submersible SDL-1 des Forces canadiennes. On compare leurs caractéristiques matérielles et électriques, ainsi que leur prix.

De tous les systèmes étudiés pour une application de 300 Ah, le meilleur est la batterie acide/plomb avec les plaques plates améliorées.

Le batterie argent/zinc, à haute énergie massique, est la seule capable de répondre au besoin prévu de 800 Ah.

INTRODUCTION

This report summarizes the state-of-the-art of conventional secondary (rechargeable) battery systems that may be used for the propulsion of small under-ice submersibles such as the Canadian Forces' SDL-1.

The battery systems to be described, namely the lead/acid, nickel/iron, nickel/cadmium, silver/zinc and the silver/cadmium all have a substantial technological background and are produced commercially. By contrast new high energy density systems such as sodium/sulphur or lithium/sulphur which might merit consideration as potential future power supplies for the propulsion of small submersibles are presently only in the conceptual or experimental stage. Kordesch (1) believes that a concentrated research effort similar to the space program will be required to develop these new power sources, while other workers in the field (2,3) predict that from five to ten years of research and development will be required before the most advanced systems will become commercially available. For convenience it was decided to consider the new systems in a subsequent report.

A review of the literature revealed that little had been published on power supplies for small submersibles, in fact, only a few reports (4,5,6,7) relating to the subject were available. The reason for the lack of information appears obvious since, according to the most recent publication (8) there are only 47 submersibles of this type in operation throughout the world. Appendix A lists these submersibles with reference to country of ownership, maximum depth, power supply, etc. It is interesting to note that 44 of the submersibles are powered by secondary batteries -- 39 by lead/acid, 3 by nickel/cadmium and 2 by silver/zinc. Of the others, two are powered by diesel engines and one by cable from the surface.

The situation regarding the procurement of improved batteries to meet the future requirements of small submersibles is not as bright as one might expect. However because of the adoption by the U.S. of the Clean Air Act of 1970, which was enacted in an attempt to reduce the pollution problem, the situation is definitely improving. The recent energy crisis brought about a revival of interest in the electrically powered vehicle. In turn, this has forced vehicle manufacturers to seek better batteries, which has provided the incentive to encourage the research electrochemist and the battery industry to explore methods to improve existing systems and to develop new high energy systems to meet the forecast requirements for traction and propulsion (9).

The five secondary battery systems to be described were selected because of their proven capability in submersible propulsion applications

and also because they are produced industrially and are commercially available. It is the general opinion of workers in the battery field (2,3,10) that these systems will provide the only power supplies able to meet the demanding power requirements of small submersibles for the next decade pending the introduction of the new high energy density systems.

It is not the purpose of this report to give a detailed description of the electrochemistry of the systems being considered. For this information the reader is directed to the literature available on the subject (11,12).

It should also be mentioned that for comparison purposes no attempt was made to normalize the batteries (cells) to a particular ampere-hour capacity. However, in order to achieve a meaningful comparison in terms of the electrical requirements of the application, only the nearest commercially available sizes were selected. In addition, these sizes were chosen so as to include a safety factor to compensate for temperature derating. The prime reasons for choosing commercially available sized batteries (cells) was to achieve maximum economy and minimize time for delivery.

ELECTRICAL REQUIREMENTS FOR SDL-1

The on-board power supply for the SDL-1 consists of a main power storage section and a low voltage storage section.

The main power storage supply required at present consists of 60 two-volt lead/acid cells rated at 342 ampere-hours (Ah) at the six-hour rate at 80°F (13). These cells are connected in series to produce 120 Vdc (nominal).

The low voltage power storage supply consists of two separate batteries to provide 12 and 28 volts respectively. The 12-volt battery is assembled from six series-connected 342 Ah two-volt lead/acid cells. The 28-volt battery is assembled from fourteen series-connected 342 Ah two-volt lead/acid cells. The 342 Ah lead/acid cell required for the application is not to exceed 48 lbs and must fit within the dimensions $13\frac{3}{4}$ in. x $6\frac{1}{2}$ in. x $5\frac{7}{8}$ in. (527 cu. in.).

In the memorandum on the SDL-1 electrical load analysis (14) it was indicated that the operational temperature of the batteries contained in the external compartment would range from 32°F to 80°F. It is known that in arctic waters, under-ice water temperatures at depths of 500 feet and greater do not rise much above 32°F. Since the SDL-1 is designed to operate at or below 500 feet, it can be expected that for the greater part of any mission the temperature of the batteries will have stabilized at or near this value. For this reason a safety factor was provided to accommodate temperature derating. The value of this factor varies from system to system.

The energy density of the original batteries used for the SDL-1 was calculated to be 11.3 watt hours per pound (Wh/lb) when discharged at the six-hour rate (80°F). This value is based on actual user experience (13).

In addition to the present requirement, the Director Maritime Engineering and Maintenance (DMEM) has advised that there now exists a new requirement to identify an economical, superior, high energy density battery suitable for use in the SDL-1. It is desirable that this battery should have a cell capacity of 800 Ah when discharged at the six-hour rate (14).

To meet the above mentioned requirement while staying within the originally defined weight and volume restrictions the battery must have an energy density of at least 26 Wh/lb and 3 Wh/cu. in.

The most promising battery systems available today are reviewed in this report from the standpoint of meeting both the current and new requirements.

SECONDARY BATTERIES FOR THE PROPULSION OF SUBMERSIBLES

Five principal secondary battery systems, commercially available today, that can be used for submersible propulsion are:

(a) lead/acid
(b) nickel/iron
(c) nickel/cadmium
(d) silver/zinc
(e) silver/cadmium

It will be observed (Table I) that lead/acid and nickel/cadmium batteries are produced in two types of construction. These can be described as the pocket plate (tubular) and the flat plate types. In general the flat plate construction is capable of higher rates of discharge.

Of the five systems, the lead/acid is the only one that uses an acid electrolyte -- sulphuric acid (H_2SO_4). The others use alkali -- potassium hydroxide (KOH).

The lead/acid battery has the highest open circuit voltage (2.14V) of these secondary systems. Silver/zinc has the next highest (1.86V). The others have an open circuit voltage of 1.34V. On discharge at medium to high rates, such as required for propulsion applications, the on-load voltages of these systems are in the same relative order. The on-load voltage of the lead/acid battery varies from 2.1 to 1.46V, the silver/zinc, 1.55 to 1.1V and the others from 1.3 to 0.8V. Unlike the lead/acid battery all the

alkaline systems have characteristically flat discharge voltage curves over 90% of the discharge range. This results in a very uniform power output during the life of the mission.

Cycle life depends on many factors, such as proper maintenance, depth of discharge, discharge rates, operational temperatures, and amount of overcharge. It is generally accepted that the major single reason for reduced cycle life and ultimate battery failure is the depth to which the battery is discharged. For details regarding the effects of other factors on battery life the reader is referred to the literature (12,15,16,17,18,19,20).

The cycle life of the lead/acid battery is least affected by the depth of discharge, due primarily to its inherent properties. On the other hand the silver/zinc battery exhibits the lowest cycle life at all depths of discharge. This is due mainly to the formation of zinc dendrites during the recharging process that eventually puncture the separator material, resulting in internal electrical shorts and early battery failure. High temperatures -- above 70°F -- which can be easily reached during high and deep discharges aggravate this problem. This accounts for the extremely poor cycle life at 100% depth of discharge. The cycle lives of the other systems are reasonably good.

The various battery systems have different charge characteristics, but generally they can be divided into two groups, those that require 5-7 hours of recharging and those that require 10-15 hours. The nickel/iron and nickel/cadmium systems can be charged at the 5-7 hour rates whereas the lead/acid and silver systems must be charged for periods of from 10-15 hours. If charged at the faster rates, the charge efficiencies of the latter systems are reduced considerably, resulting in a loss of battery capacity.

The sintered nickel/cadmium system in conjunction with proper charge control devices can be charged at even higher rates -- up tc 1 hour rate. This however requires the use of a charge controller designed for the specific sized battery being considered (21).

PRESSURE EQUALIZATION SYSTEMS

Pressure equalization systems are required when batteries are to be mounted external to the pressure hull of a submersible. Several advantages result from placing the battery in such a compartment. The buoyant effect of the water displaced by an externally mounted battery is a positive factor. For example, the density of an 800 Ah size silver/zinc battery is calculated to be 135 lbs/cu. ft.; the seawater displaced at 64 lbs/cu. ft. adds significantly to the buoyancy. In effect, this results in significant reductions in the net displacement and size of the pressure hull. Therefore

the hull thickness can either be reduced or the submersible can go deeper. Another important advantage is that externally mounted batteries can be jettisoned in an emergency.

There are a number of problems associated with the operation of externally mounted batteries in a deep ocean environment. Batteries must operate at tilt angles up to 60 degrees from the vertical during underwater manouvers and are often subjected to rapid changes in water pressure during ascent and decent. However, the enormous hydrostatic pressures which are encountered impose the greatest operational problems. Aside from the structural stress considerations, batteries evolve gases which must be vented while seawater must be excluded. These problems are resolved by the pressure equalization compartments.

Other difficulties further complicate battery operation. Oil, used as the pressure compensating fluid, must be prevented from contacting the active plate material at maximum tilt angles and high pressures. Out-gassing of cells occurring during ascent can force electrolyte to carry over into the outer oil compartment resulting in corrosion to cell tops and other components. The latter problem is minimized by the use of gas entrainment devices (5).

Aside from the factors mentioned above which could adversely affect battery life (oil, corrosion, etc.), the electrical performance of the silver/zinc battery system used within a pressure equalization container differs little from its performance at atmospheric pressure and comparable temperatures. On the other hand it has been found that lead/acid batteries charged under normal atmospheric conditions (80°F, 0 psig) and discharged under deep sea pressures show an improvement of approximately 15% in watt-hour and ampere-hour capacity (6). This improvement is attributed to deeper electrolyte penetration into pores of the plates. However, lead/acid batteries which are both charged <u>and</u> discharged under high pressures exhibit a capacity loss. Low temperatures further aggravate battery performance.

Pressure equalization systems are available from several battery manufacturers. The cost quoted by a silver battery manufacturer for his pressure equalization system was 15% to 30% of battery cost (approximately $17,000). Similar externally mounted systems exist for lead/acid and nickel batteries. Although no prices were quoted by the respective battery manufacturers, it is anticipated that their costs would be somewhat less.

EFFECT OF TEMPERATURE ON BATTERY PERFORMANCE

The rate of an (electro)chemical reaction is temperature dependent. It approximately doubles for each 18°F rise in temperature and conversely

halves for each 18°F drop. It is known that halving the chemical rate of reaction has essentially the same effect on battery (cell) performance as doubling the rate of discharge (for example, 6 hr rate to 3 hr rate). The ampere-hour capacity of batteries diminishes with decreasing temperature.

Table II compares battery performance at the 6 hr discharge rate, at 80°F and 32°F. As previously explained the latter temperature (32°F) is considered very important because it is believed that this will be the approximate operational temperature of the SDL-1 within the ocean environment. The 48°F temperature differential (80°F minus 32°F) literally means that at 32°F the battery is discharging at the equivalent of the one hour rate at 80°F. The temperature derating factor has been taken into account in the selection of cell sizes with regard to Ah capacity. Of all the systems, the capacity of the lead/acid shows the greatest loss when exposed to 32°F. Percentage-wise this loss can amount to 27 percent (22). However, manufacturers now claim that with today's improved batteries these losses have been reduced to 10-15 percent. In this study the latter value was adopted for use as the temperature derating factor. On the other hand, the capacity of the nickel/cadmium battery is the least affected at 32°F.

The midpoint potentials quoted in Table II represent the average value of the discharge voltage at the 6 hour rate. This value is significant since it was used to calculate the energy and power densities of the systems under consideration. Energy density is expressed as either watt hours per pound or watt hours per cubic inch. Power density is expressed as watts per pound.

Despite the fact that the lead/acid battery has the highest midpoint potential, its energy and power densities are seriously degraded because of the high weight of its lead components. The silver/zinc battery has the highest energy and power density values at both 80°F and 32°F. Its values are approximately twice that of the nearest competitor, namely silver/cadmium. The high performance of the silver/zinc battery can be attributed directly to the high energy content of its active materials.

CELLS TO MEET PRESENT REQUIREMENTS: PHYSICAL/ECONOMIC CONSIDERATIONS

The present requirement of the SDL-1 demands a 300 Ah capacity battery. To meet this demand and at the same time compensate for the effect of temperature derating will require that the capacity of the candidate battery be up-graded to approximately 340 Ah (80°F - 6h rate). As mentioned in the introduction, the cells listed in Table III were selected from the nearest commercially available sizes. This selection accounts for the slight variation in basic cell capacities.

A comparison of the cell weights of these production batteries clearly indicates the advantage of the silver systems. These systems are only one-third to one-quarter the weight of the others. With respect to cell volume the silver systems also have about the same advantage.

The latest energy density figures (Wh/lb) as quoted by the manufacturers for 1975 production batteries and shown in Table III indicate an improvement of 10 to 30 percent over earlier designs. This improvement can be largely attributed to the use of lighter case materials and improved electrode construction. Despite the claims made for the superiority of the tubular versus flat plate lead/acid construction (23), recent manufacturer's information indicates that an improved flat plate type has a 25 percent greater energy density than the tubular type. The values quoted in Table III reflect this improvement.

The cost in 1975 dollars of the various 300 Ah secondary cells is compared in Table III. Included are the cost, per Ah, per KWH, and per cell. Costs were tabulated in this way to facilitate selection where these parameters are being considered. In general, regardless of any given parameter the costs are relative.

It will be noted that the least costly cell currently available is the lead/acid flat-plate construction. As might be expected the silver batteries are the most expensive due to the high cost of the silver content ($4.50 oz) and more involved fabrication techniques. Cadmium being more expensive than zinc, accounts for the silver/cadmium cell being costlier than the same size silver/zinc cell. The high cost of the silver systems has limited their use mainly to applications where cost is not a primary consideration, such as in military and space applications. However, in the case of the SDL-1 type of mission where the submersible returns to its base, the silver from expended batteries may be collected and reclaimed, and the cost -- minus processing charges -- can be recovered.

In the silver systems 0.15 oz (troy) of silver are required for each Ah of capacity per cell. Both the 350 Ah silver/zinc and 350 Ah silver/cadmium cells individually contain 52.5 oz (troy) of silver. At the current market price of $4.50/oz (troy), this amount of silver would cost $236. Assuming a 20% processing charge for the reclaiming of silver from expended cells the recovered value of the silver can amount to approximately 30% of the price of subsequently purchased 350 Ah silver cells. When projected to 350 Ah batteries, the savings would amount to $20,000 for the 107 cell silver/zinc battery and $28,000 for the 147 cell silver/cadmium battery.

Since 300 Ah nickel/cadmium cells are not commercially available, the expedient solution to the problem of obtaining the required capacity, was to parallel four 85 Ah cells together. Although the paralleling of cells is not generally desirable, because of maintenance difficulties, it represents an option that should be considered. The alternative is to procure an essentially small number of custom made batteries at much higher costs. This may be justified and might be investigated should a decision be reached to use nickel/cadmium batteries and thus avoid the paralleling of a prohibitively large number of cells.

HIGH CAPACITY CELLS TO MEET NEW REQUIREMENT

It was stated in the section on electrical requirements that to replace the present 300 Ah battery by an 800 Ah battery within the same weight and volume restrictions would necessitate the use of a battery system having an energy density of at least 26 Wh/lb and 3 Wh/cu. in.

At present the silver/zinc system is the only one that has an energy density capable of meeting this requirement. Its energy density is 40 Wh/lb and 3 Wh/cu. in. at the 6h rate.

For purposes of comparison all the systems are listed in Table IV. Previous comments made regarding physical and economic considerations for the 300 Ah cells (Table III) can be equally applied to the larger 800 Ah cells.

Again, since 800 Ah nickel/cadmium cells are not commercially available it will be necessary to parallel smaller size cells together of either the pocket plate or sintered plate types. Two 450 Ah pocket plate cells and four 230 Ah sintered plate cells are required to obtain the desired capacity.

The cost per Ah of the larger cells is in general lower than the cost per Ah of the 300 Ah cells, except where cells had to be paralleled. If the cost of cells were based on the cost of components alone the costs would be relative, however since the cost of labour involved in the assembly remains approximately the same for both sizes, the 800 Ah cells are more economical to purchase. For example, the unit Ah cost of an 800 Ah silver/zinc and silver/cadmium cell is approximately 33 percent less than the smaller cell.

In the case of the nickel/cadmium systems as already mentioned, it is necessary to parallel cells in order to obtain the higher capacity desired. This, of course, results in no direct savings in dollars per Ah.

It should be noted that as the lead/acid, nickel/iron, and nickel/cadmium systems cannot meet the minimum energy density requirement, they cannot be considered for the higher capacity cell application.

Governments can purchase silver/zinc cells under two contractual methods. One, is to provide the silver as Government Furnished Material (GFM) which the contractor processes for plate fabrication. In this case the manufacturer's charges would include the cost of labour, materials (excepting silver) and fabrication. An 800 Ah silver/zinc cell requires approximately 110 troy ounces of silver. Unless the government has recoverable silver on hand or can procure silver at less than the market price, there

is no economy involved.

The other method of purchase is to buy the cell including the silver directly from the manufacturer. The price of the silver/zinc cell shown in Table IV includes manufacturer supplied silver. As was previously mentioned, a substantial savings in the price of a silver battery can be achieved by reclaiming silver from expended batteries. In the case of the 800 Ah (107 cell) silver/zinc battery the savings would amount to $46,000 or approximately 45% of the price of battery (Table VIII). Similarily, the savings with an 800 Ah (147 cell) silver/cadmium battery would amount to $63,500 or 40% of the quoted purchase price (Table VIII). If consideration is given to the reclamation of silver, then the cost of silver/zinc cells using reclaimed silver will approach the price of the nickel systems.

LOW AND MAIN VOLTAGE POWER STORAGE (300 Ah)

Low voltage dc power is provided by two separate banks of cells. One bank of 300 Ah cells provides a 12-volt supply, the other bank provides 28 volts. The main power storage 120-volt dc supply is derived from a separate bank of 300 Ah cells.

Table V lists the various candidate 300 Ah battery systems. It shows the number of cells required per battery, (which vary from system to system because of differences in cell voltages) and compares cost, physical properties and electrical power outputs.

It will be noted that an exceptionally large number of cells are required by the nickel/cadmium sintered system. As was explained earlier, the unavailability of a 340 Ah cell size necessitated the paralleling of four 85 Ah cells, the closest size commercially available. As the voltage requirement increases, the number of cells increases proportionately -- 400 (85 Ah) cells would be required for the main power storage supply. Paralleling such a large number of cells would present a major maintenance problem since it would be most difficult to maintain proper cell balance. It would definitely be an advantage maintenance-wise to have the proper size (300 Ah) cells.

Details of the complete power supply system (main power and low voltage power storage) are summarized in Table VI in terms of total number of cells, total weight and volume, energy, battery cost and cost of cycling. Of all the candidate battery systems considered for the 300 Ah application, the flat plate lead/acid battery best meets the overall requirements. It is superior to the nickel systems in size, weight, number of cells and comparable in power output. However its main advantage is its cost -- about one-quarter that of the least expensive nickel system. Although by comparison the

silver systems have a marked advantage in size and weight, they are 8 to 15 times more costly than the flat plate lead/acid battery (even with the credit for reclaimed silver taken into account). Even though the lead/acid battery does not have the best cycle life of the systems listed, nevertheless it is the most economical in terms of cost per cycle.

LOW AND MAIN VOLTAGE POWER STORAGE (800 Ah)

The voltage requirements for the low and main power supplies are identical for both the 300 Ah and 800 Ah batteries (that is, 12, 28 and 120 volts).

The comments which were made with regard to high capacity cells for the 800 Ah requirement also apply to 800 Ah batteries. To reiterate, the silver/zinc system is the only one that at the present time has an energy density capable of meeting the capacity requirements within the weight and volume restrictions.

Table VII compares the silver systems with the other 800 Ah battery systems for the 12, 28 and 120 volt power supplies with regard to the number of cells, physical properties, power outputs and costs.

Table VIII summarizes these parameters for the complete batteries together with the cycle life and cost per cycle.

While the silver/cadmium battery can be discharged to 100% D.O.D. without seriously degrading its cycle life, the cycle life of the silver/zinc battery is extremely dependent on the depth of discharge (D.O.D.). To extend silver/zinc battery life, every precaution should be taken to not exceed 80% D.O.D. except, of course, in the case of an emergency where this reserve of power is needed.

If overall cost is not a major deterrent, then the only acceptable choice for the 800 Ah application is the silver/zinc system, until other less expensive high energy density systems become available.

OPERATIONAL POWER LIMITS

For design and operational purposes it is useful to know the safe power levels that can be withdrawn from the batteries without resultant damage. Regardless of the system selected for the SDL-1 submersible, care must be exercised that certain safe limits not be exceeded.

Table IX shows the power densities that can safely be obtained from the battery systems under various operational conditions. The maximum continuous power density which may be withdrawn for periods up to a few minutes, and the peak power density -- for a period up to one minute -- are given. These values are compared with the power density at the six-hour rate. As might be expected the silver/zinc battery has the highest power density values at all rates. At the high rates, the sintered nickel/cadmium and the silver/cadmium have essentially the same power density. The flat plate lead/acid battery has the next highest power density.

The higher power densities which can be obtained from the batteries under maximum continuous and peak power conditions are only achieved at the expense of available battery capacity, for example, even at the one-hour rate of discharge, the effective capacity of the lead/acid battery drops to 65% of the six-hour rated capacity. Capacity losses are even more pronounced at higher rates of discharge.

In view of the foregoing and where maximum battery life is desired, users should attempt, wherever possible, to not exceed the safe power limits listed in the Table.

PERFORMANCE PROJECTIONS

A considerable amount of research and development work directed towards improving the performance of the secondary battery systems is currently in progress in many countries -- U.S.A., England, Japan, Russia and Canada.

Within the next few years -- by 1980 -- it is expected that significant improvements to the existing secondary systems will be achieved. No major breakthroughs that might result in energy densities approaching the theoretical values are anticipated. However, improvements ranging from 25% to 100% in energy density and cycle life are forecast. An improvement to approximately 25% is the maximum predicted for the silver systems. The systems presently exhibiting the lowest energy densities -- lead/acid, nickel/iron, nickel/cadmium -- show promise for the greatest improvement -- up to 100%.

Table X lists the performance parameters of the various secondary battery systems, showing present status and the improvements that might be expected by 1980. The battery systems that are available today are the result of many years of research and development and therefore improvements beyond those predicted are highly unlikely.

CONCLUSIONS AND RECOMMENDATIONS

Of all the candidate battery systems considered for the SDL-1 300 Ah application, the improved type of flat plate lead/acid battery best meets the overall requirements. It is superior to the nickel systems in size, weight, number of cells, and comparable in power output. Its principal advantage is its cost, about one-quarter that of the least expensive nickel system and about one-tenth of the silver system. The flat plate lead/acid battery is also most economical to use on a cost per cycle basis. These batteries are readily available from the manufacturers' Canadian branches.

For the 300 Ah SDL-1 application, it is recommended that the improved type of flat plate lead/acid battery be adopted.

In order to meet the SDL-1, 800 Ah application, the candidate battery system must have an energy density of at least 26 Wh/lb and 3 Wh/cu. in. At present the silver/zinc system is the only one that is capable of meeting this stringent energy density requirement. It is therefore recommended that the silver/zinc battery system be used for the 800 Ah application.

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REFERENCES

1. K.V. Kordesch, "Modern Aspects of Electrochemistry", No. 10, Edited by J.O'M. Bockris and B.E. Conway, Plenim Press, New York, pp 339-443, 1975.

2. D.L. Douglas, "The Impact of Advanced Batteries on Electrical Power Generation", IEEE Conference on Energy Development, pp 37-41, 1974.

3. E.J. Cairns and J. McBreen, "Batteries Power Urban Autos", Industrial Research, pp 57-60, June 1975.

4. J.J. Myers, H.H. Cahl and R.F. McAlister, "Handbook of Ocean and Underwater Engineering", Edited by J.J. Myers, McGraw-Hill Book Co., pp 6-1 to 6-18, 1969.

5. D.F. Momsen, and J.C. Clerici, "First Silver Zinc Batteries Used in Deep Submergence", Marine Technological Journal, March-April 1971.

6. K.K. Berju, E.M. Daniels, and E.M. Strohlein, "Characteristics of Lead Acid and Silver Zinc Batteries in the Deep Ocean Environment", Proceedings of the Marine Electrochemical Symposium, October 1972.

7. G.W. Work and S. Fried, "Silver/Zinc Battery Power for Deep Ocean Vehicles", Proceedings of SAE, National Power Plant Meeting, Cleveland, Ohio, October 1969.

8. <u>Jane's Ocean Technology 1974-75</u>, Edited by R.L. Trillo, Jane's Yearbooks (London) pp 3-41 (1975).

9. Proceedings of the Symposium on Batteries for Traction and Propulsion, March 7-8, 1972, Sponsored by the Columbus Section of the Electrochemical Society, Columbus, Ohio, 1972.

10. N.R. Iammartino, "New Batteries are Coming", Chemical Engineering, pp 48-50, January 1975.

11. C.K. Morehouse, R. Glicksman and G.S. Lozier, "Batteries", Proceedings of the I.R.E., pp 1462-1463, August 1958.

12. G.W. Vinal, "Storage Batteries", John Wiley and Sons (New York) 1955).

13. DMEM-3, "Private communication", 21 October 1975.

14. Memorandum, R.C. Smith, "SDL-1 Electrical Load Analysis", 29 May 1972.

15. DMEM-3, "SDL-1 on Board Power Supply", Memorandum 11900-SDL-1 (DMEM-3), 24 January 1975.

16. S. Falk and A. Salkind, "Alkaline Storage Batteries", J. Wiley and Sons, New York (1969).

17. P.L. Howard, "The Silver Zinc Rechargeable Battery", Technical Bulletin, Yardney Electric Corp. 1957.

18. P.L. Howard, "The Silver Oxide-Cadmium Alkaline Secondary Battery", Technical Bulletin, Yardney Electric Corp., 1957.

19. E040-5EA-2, "Description and Maintenance Instructions Aircraft Nickel-Cadmium Storage Batteries (Sintered Plate - Vented Type)", Canadian Forces, February 1971.

20. Candian Forces Technical Order, C-93-010-002/MF000, "Maintenance, Lead Acid Batteries".

21. R.L. Haines, I.H.S. Henderson, J.R. McKague and T.E. King, "Coulometric Control of Charging of Ni-Cd Secondary Batteries", DCBRL Report No. 499, May 1966.

22. P.L. Howard, "Wet-Cell Batteries for Power", Product Engineering, pp 75-82, 15 February 1960.

23. F.P.A. Odenkirchen, "Tubular Versus Flat Plate Positives in Motive Power Applications", Technical Bulletin, ESB Canada Limited, 1974.

TABLE I

Secondary Batteries for Submersible Propulsion

Battery System	Cathode Positive	Anode Negative	Electrolyte	Cell Voltage O.C.(a)	Cell Voltage O.L.(b)	Cycle Life at 50% D.O.D.(c)	Cycle Life at 80% D.O.D.	Cycle Life at 100% D.O.D.
Lead/Acid	PbO_2	Pb	H_2SO_4	2.14	2.1-1.46	1000+	750	500
Nickel/Iron	NiO_2	Fe	KOH	1.34	1.3-0.75	1000+	500	300
Nickel/Cadmium	NiO_2	Cd	KOH	1.34	1.3-0.75			
(a) Pocket Plate						3000	1000	100
(b) Sinter Plate						1000	500	250
Silver/Zinc	AgO	Zn	KOH	1.86	1.55-1.1	200	70	3-6
Silver/Cadmium	AgO	Cd	KOH	1.34	1.3-0.8	500	300	200

(a) O.C. - Open Circuit
(b) O.L. - On Load
(c) D.O.D. - Depth of Discharge

TABLE II

Effect of Temperature on Performance of Secondary Batteries
Discharge - 6H Rate

Battery System	Potential at Midpoint		Capacity (AH) % Rated		Energy Density Wh/lb		Energy Density Wh/in^3		Power Density W/lb	
	80°F	32°F	80°F	32°F	80°F	32°F	80°F	32°F	80°F	32°F
Lead/Acid	1.92	1.90	100	73	13	8.8	0.91	0.65	2.0	1.5
Nickel/Iron	1.20	1.07	100	80	12	8.4	0.73	0.59	1.7	1.4
Nickel/Cadmium	1.23	1.19	100	92	11.4	10.1	0.87	0.77	1.9	1.7
Silver/Zinc	1.52	1.48	100	95	40	38	3.15	3.9	7.8	7.0
Silver/Cadmium	1.08	1.06	100	91	27	24	1.78	1.6	4.5	4.0

TABLE III

Comparison of Weight-Volume-Cost of 300 AH Secondary Cells

Cell Type	80°F Capacity at 6H Rate		Cell Wt. (lbs)	Cell Volume (in^3)	Wh/lb	Cost 1975 Dollars		
	AH	KWH				$/AH	$/KWH	$/Cell
Lead/Acid (Tubular)	330	0.638	51	509	13	0.30	154	98
Lead/Acid (Flat Plate)	332	0.634	39.3	413	16.1	0.21	110	70
Nickel/Iron	324	0.389	35.3	453	12	0.68	566	220
Nickel/Cadmium (Pocket Plate)	320	0.384	42	468	9	0.54	453	174
Nickel/Cadmium (Sintered Plate)	340 [a]	0.408	26.3 [b]	336 [b]	15	0.78	652	266
Silver/Zinc	350	0.525	13.8	168	40	1.85	1230	646
Silver/Cadmium	350	0.385	13.5	167	27	2.02	1840	708

(a) One 340 AH cell consists of four 85 AH cells in parallel.
(b) Weight and volume of four 85 AH cells.

TABLE IV

Comparison of Weight-Volume-Cost of 800 AH Secondary Cells

Cell Type	80°F Capacity at 6H Rate		Cell Wt. (lbs)	Cell Volume (in^3)	Wh/lb	Cost 1975 Dollars		
	AH	KWH				$/AH	$/KWH	$/Cell
Lead/Acid (Tubular)	900	1.75	129	1328	13	0.26	131.4	230
Lead/Acid (Flat Plate)	900	1.73	107	1058	16.1	0.21	107.5	186
Nickel/Iron	864	1.04	82.9	1076	12	0.60	500	520
Nickel/Cadmium[(a)] (Pocket Plate)	900	1.08	115	1208	9	0.53	444	480
Nickel/Cadmium[(b)] (Sintered Plate	920	1.10	80.4	972	15	1.04	873	960
Silver/Zinc	800	1.20	30	378	40	1.22	810	972
Silver/Cadmium	800	0.88	29.3	367	27	1.33	1210	1065

(a) One 900 AH cell consists of two 450 AH cells in parallel.
(b) One 920 AH cell consists of four 230 AH cells in parallel.

TABLE V

Batteries for Power Storage
Comparison and Cost of 300 AH Systems

Type	12 Volt Battery					28 Volt Battery					120 Volt Battery				
	Cells No.	Wt. lbs	Vol. Ft^3	Energy KWH	Cost $ (1975)	Cells No.	Wt. lbs	Vol. Ft^3	Energy KWH	Cost $ (1975)	Cells No.	Wt. lbs	Vol. Ft^3	Energy KWH	Cost $ (1975)
Lead/Acid (Tubular)	6	306	1.77	3.83	588	14	714	4.12	8.93	1370	60	3060	17.7	38.3	5880
Lead/Acid (Flat Plate)	6	236	1.44	3.8	420	14	550	3.36	8.87	980	60	2360	14.4	38	4200
Nickel/Iron	10	353	2.62	3.89	2200	24	847	6.29	9.34	5280	100	3530	26.2	38.9	22000
Nickel/Cadmium (Pocket)	10	420	2.71	3.84	1740	24	1008	6.5	9.22	4180	100	4200	27.1	38.4	17400
Nickel/Cadmium (Sintered)	40[(a)]	263	1.94	4.08	2660	96	631	4.7	9.8	6380	400	2630	19.4	40.8	26560
Silver/Zinc	8	111	0.84	4.2	5170	19	263	2.0	10.0	12270	80	1100	8.4	42	51680
Silver/Cadmium	11	149	1.07	4.2	7790	26	351	2.52	10.0	18410	110	1400	10.7	42.4	77880

(a) One 340 AH cell consists of four 85 AH cells in parallel.

TABLE VI

Complete Power Storage Systems for SDL-1
Comparison and Cost of 300 AH Batteries

Type	(12V - 28V - 120V) Batteries						
	Cells No.	Weight lbs	Volume Ft^3	Energy KWH	Cost $ (1975)	Cycle of Life 50% D.O.D.	Cost(b) $ Per Cycle
Lead/Acid (Tubular)	80	4080	23.6	51.1	7840	1000	8
Lead/Acid (Flat Plate)	80	3140	19.2	50.7	5600	1000	6
Nickel/Iron	134	4730	35.1	52.1	29480	2000	15
Nickel/Cadmium (Pocket)	134	5630	36.3	51.5	23320	3000	8
Nickel/Cadmium (Sintered)	536 (a)	3520	26.1	54.7	35600	1000	36
Silver/Zinc	107	1480	14.6	56.2	69120	200	346
Silver/Cadmium	147	1990	14.3	56.6	104100	500	208

(a) One 340 AH cell consists of four 85 AH cells in parallel.
(b) Cost of recharge not included.

TABLE VII

Batteries for Power Storage
Comparison and Cost of 800 AH Systems

Type	12 Volt Battery					28 Volt Battery					120 Volt Battery				
	Cells No.	Wt. lbs	Vol. Ft^3	Energy KWH	Cost $ (1975)	Cells No.	Wt. lbs	Vol. Ft^3	Energy KWH	Cost $ (1975)	Cells No.	Wt. lbs	Vol. Ft^3	Energy KWH	Cost $ (1975)
Lead/Acid (Tubular)	6	774	4.61	10.5	1380	14	1800	11.0	24.5	3220	60	7740	46.1	105	13800
Lead/Acid (Flat Plate)	6	642	3.67	10.4	1120	14	1500	8.57	24.2	2600	60	6420	36.7	104	11160
Nickel/Iron	10	829	6.23	10.4	5200	24	1990	14.94	24.9	12480	100	8290	62.3	104	52000
Nickel/Cadmium[a] (Pocket)	20	1150	6.99	10.8	4800	48	2760	16.8	25.9	11520	200	11500	69.9	108	48000
Nickel/Cadmium[b] (Sintered)	40	804	5.25	11.0	9600	96	1930	13.5	26.4	23040	400	8040	52.5	110	96000
Silver/Zinc	8	240	1.76	9.6	7780	19	570	4.25	22.8	18470	80	2400	17.7	96	77760
Silver/Cadmium	11	322	2.33	9.7	11720	26	762	5.52	22.9	27690	110	3220	23.3	97	117150

(a) One 900 AH cell consists of two 450 AH cells in parallel.

(b) One 920 AH cell consists of four 230 AH cells in parallel.

TABLE VIII

Complete Power Storage Systems for the SDL-1
Comparison and Cost of 800 AH Batteries

Type	(12V - 28V - 120V) Batteries						
	Cells No.	Weight lbs	Volume Ft^3	Energy KWH	Cost $ (1975)	Cycle Life 50% D.O.D.	Cost (c) $ Per Cycle
Lead/Acid (Tubular)	80	10320	61.7	140	17400	1000	17
Lead/Acid (Flat Plate)	80	8560	48.9	123	14800	1000	15
Nickel/Iron	134	11110	83.6	139	69680	2000	35
Nickel/Cadmium[(a)] (Pocket)	268	15410	93.7	145	64320	3000	21
Nickel/Cadmium[(b)] (Sintered)	536	10770	75.4	147	128640	1000	128
Silver/Zinc	107	3210	23.7	128	104000	200	520
Silver/Cadmium	147	4310	31.2	130	157000	500	314

(a) One 900 AH cell consists of two 450 AH cells in parallel.

(b) One 920 AH cell consists of four 230 AH cells in parallel.

(c) Cost of recharge not included.

TABLE IX

Comparison of Power Densities of the Secondary Battery Systems for SDL-1 Application

Battery System	Power Density (80°F) 6-H Rate W/lb	Maximum Continuous* W/lb	Peak** W/lb
Lead/Acid (Tubular)	2.3	30	65
Lead/Acid (Flat Plate)	2.8	40	80
Nickel/Iron	2.1	20	40
Nickel/Cadmium (Pocket)	1.7	28	66
Nickel/Cadmium (Sintered)	1.90	65	135
Silver/Zinc	7.8	200	385
Silver/Cadmium	5.8	65	130

*Maximum Continuous - without damage to the battery, period of a few minutes only.

**Peak power - High rate discharges as required for engine starts and maximum duration of seconds to a minute or so.

TABLE X

Performance Projections of Candidate Secondary Batteries

Battery System	Cell Voltage	Theor. WH/lb	Achieved			Projected			
			WH/lb	W/lb	Cycles(a)	WH/lb	W/lb	Cycles(a)	Year
Lead/Acid	2.1	80	16	30	1000	20-30	40-50	1500	1978-80
Nickel/Iron	1.34	120	12	20	2000	15-25	20-30	3000	1978-80
Nickel/Cadmium	1.34	100	15	65	3000	20-25	65-80	>3000	1980
Silver/Zinc	1.86	210	40	200	200	40-50	200-220	>200	1980
Silver/Cadmium	1.34	140	27	65	500	30-40	65-80	>500	1980

(a) Cycle life based on 50% D.O.D.

APPENDIX A

SMALL SUBMERSIBLES

Country	Submersible	Max. Depth Ft.	Manufacturer	Power Supply	Completed
Canada	PISCES I	1,500	HYCO	Lead-Acid	1965
	PISCES II	2,400	HYCO	Lead-Acid	1969
	PISCES III	3,500	HYCO	Lead-Acid	1969
	PISCES SDL-1	2,000	HYCO	Lead-Acid	1970
	PISCES IV	6,600	HYCO	Lead-Acid	1972
	PISCES V	6,600	HYCO	Lead-Acid	1973
	PISCES VI	6,600	HYCO	Lead-Acid	1975
	PISCES VII	6,600	HYCO	Lead-Acid	1975
	PISCES VIII	3,000	HYCO	Lead-Acid	1975
	PISCES IX	6,600	HYCO	Lead-Acid	1976
	PISCES X	2,400	HYCO	Lead-Acid	1976
	AQUARIUS I	1,200	HYCO	Lead-Acid	1973
	TAURUS I	1,200	HYCO	Lead-Acid	1976
	NARWAL PS-1	1,025	Perry Sub. Ltd. (US)	Nickel-Cadmium	
	ACCESS PS-2	1,025	Perry Sub. Ltd. (Can.)	Lead-Acid	
France	GRIFFON	1,968	C.E.R.T.S.M.	Nickel-Cadmium	1973
	ARCHIMEDE	36,080	D.T.C.N.	Nickel-Cadmium	1961
	DIVING SAUCER	984	C.E.M.A.	Lead-Acid	1970
Germany	MERMAID I	1,000	Bruker-Physik AG	Lead-Acid	1971
	MERMAID II 002	825	Bruker-Physik AG	Lead-Acid	1973
	MERMAID II 003	825	Bruker-Physik AG	Lead-Acid	1973
	ARGUS I	984	Mashinengau Gabler	Lead-Acid	1971
Japan	HAKUYO	984	Kawasaki Industries	Lead-Acid	1971
	YOMIURI-GO	984	Mitsubishi Industries	Diesel/Lead Acid	1964

Country	Submersible	Max. Depth Ft.	Manufacturer	Power Supply	Completed
U.S.A.	ASHERAH	600	General Dynamics	Lead-Acid	
	STAR II	1,200	General Dynamics	Lead Acid	
	STAR III	2,000	General Dynamics	Lead-Acid	1966
	NEKTON ALPHA	1,000	General Oceanographics	Lead-Acid	1968
	BETA	1,000	General Oceanographics	Lead-Acid	1971
	GAMMA	1,000	General Oceanographics	Lead-Acid	1971
	ALVIN	11,500	Litton Industries	Lead-Acid	1964
	DEEP QUEST	6,000	Lockheed Missiles Co.	Lead-Acid	1967
	OPSUB	2,000	Ocean Systems Inc.	Cable from Surface	1971
	PC-8	1,200	Perry Oceanographics	Lead-Acid	
	PC-14	1,200	Perry Oceanographics	Lead-Acid	
	ALUMINAUT	15,000	Reynolds International	Silver-Zinc	1964
	MAKAKAI	600	Nav. Undersea Center	Lead-Acid	1972
	DEEP VIEW	600	USN Undersea Center	Lead-Acid	1972
	DEEPSTAR 2000	2,000	Westinghouse El. Corp.	Lead-Acid	
	DEEPSTAR 4000	4,000	Westinghouse El. Corp.	Lead-Acid	
	BEAVER MK IV	2,000	North Am. Rockwell	Lead-Acid	1968
	TRIESTE II	36,000		Lead-Acid	
	MORAY	6,000		Silver-Zinc	
USSR	SEVER-2	6,560	Soviet State Design Inst.	Lead-Acid	
	GVIDON	820	VNIRO	Lead-Acid	1970
	TINRO I	1,000	Built in Leningrad	Diesel Engine	1965
	TINRO II	1,000	Built in Leningrad	Diesel Engine	1973
United Kingdom	The only submersibles reported to have been manufactured in the UK were of the DOLPHIN MK II type, a two-man wet diver transport vehicle. Three were produced in 1973 with another five on order. It should be noted that the Canadian built PISCES I, II, III, VIII, and X are owned and operated by Vickers Oceanics. AQUARIUS I and TAURUS I were sold to P&O SUBSEA also in the U.K. PISCES V owned by HYCO is located in the U.K.				

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This report reviews candidate secondary battery systems that can be used for the propulsion of the Canadian Forces SDL-1 submersible. These battery systems are compared in terms of their physical and electrical characteristics and cost.

Of the power sources considered, the improved flat plate lead acid battery is the most suitable choice to meet the present 300 Ah application.

The silver/zinc system with its high energy density is the only one capable of meeting the forecast 800 Ah requirement.

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